A Review on Interesting Properties of Chicken Feather as Low-Cost Adsorbent

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Abstract: Adsorption process has been used widely in the treatments related to environmental issues due to its modestness and ease of operation. Through the years, the development of low-cost absorbents has been given much attention in the adsorption process. The applications of chicken feather, a byproduct in poultry farming on wastewater treatment are boon for the worldwide researchers. In this review paper, the possible mechanism of adsorption, the adsorption isotherms and the factors affecting the adsorption process are first discussed. Next, this paper provides a review on the potential low-cost adsorbent of chicken feather: its composition, morphological structure and properties. This paper also describes the preparation of chicken feather as an adsorbent with different activation methods. The unique morphological structure of chicken feather enhances its interesting properties for several types of applications purposes. Lastly, the applications of chicken feather proved by the past studies are presented in this paper.

Keywords: Adsorption, Langmuir, Freundlich, chicken feather

1. Introduction

In the modern era of globalization, the increase of population in our world has increased the risk of environmental pollution. The main sources of environmental pollution are the industrial and agricultural activities. The rapid industrialization of human society produces different contaminants or pollutants in wastewater that may release to the environment and create a major global concern nowadays [1]. Heavy metals are the alarming pollutants in the industrial effluents due to their non-destructive nature, toxicity, bioaccumulation and subsequent biomagnifications [2]. Heavy metals such as arsenic, cobalt, copper, iron, mercury, lead and zinc are the most commonly encountered metals in the industrial wastewater from mining, battery and chemical manufacturing industries [1]. In fact, heavy metals are the essential trace elements for living creatures in the world including human, animals and plants. However, large amounts of heavy metals may lead to acute and toxicity.

Besides, the discharge of coloured effluents from the textile dyeing industry is one of the major causes of water pollution today [3]. The water colour is an apparent indicator of water pollution due to the presence of dyes. Dyes which are the most problematic pollutants can be grouped into several structural varieties such as acidic, basic, azo, diazo, disperse, anthraquinone based as well as metal complex dyes. Apart from that, another environmental challenge is the production and storage of hydrogen gas (H_2). In future, an H_2 economy based on renewable energy is expected to have a significant impact on the energy distribution [4]. This is because H_2 is not available as individual elements in the atmosphere and it is the lightest gas in the world, thus it is not held by the earth's gravity.

Being the utmost importance of environment towards living creatures in the world, the demand of its quality rehabilitation and preservation are the major concerns of this century. Literature reports that the adsorption process is one of the widely used methods to deal with the wastewater treatment. Adsorption is advantageous, especially when the metal concentrations range from 1 mg/L to 100 mg/L [5]. There are many absorbents used nowadays which are

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generated from different sources of materials such as household wastes, agricultural products, industrial wastes, sea materials, soil and ore materials [6]. In the past, there are four types of generic adsorbents dominating the commercial use of adsorbents which are activated carbon, activated alumina, silica gel and zeolites [7]. However, these adsorbents are economically not efficient, thus cannot be used in a large scale. Therefore, the development of low-cost absorbents had been an attempt for the researchers. They had searched for the new way about cheap precursor as absorbent by reducing the cost of raw materials. In the development of low-cost adsorbents, the selection of the precursor depends upon several factors especially inexpensive, high availability, and non-hazardous in nature. The types of these precursors can be divided into organic and inorganic [6].

2. Adsorption as Water and Wastewater Treatment Option

Adsorption is a surface phenomenon that takes place when a gas or liquid solute is adhered onto an adsorbent's surface, forming a film of adsorbate. An adsorbate is any substance which is removed from its gas or liquid phase at the interface. The term sorption encompasses both processes of adsorption and desorption which is the reverse of adsorption. Due to the development of the sorbent and cyclic process, adsorption has been developed as a key separations tool in industries especially the chemical industry [7]. This technique has been well-established and widely used for the industrial effluent treatment of a variety of water pollutants. For instance, adsorption approach has been adopted by Wang et al. [8] in the treatment of heavy metals by using graphene oxide-based silica materials. Activated carbon synthesized from apricot stones was applied by Djilani et al. [9] for the removal of Methyl Orange via adsorption process. Similar technique has been used for the removal of a variety of pesticides in the study of Ruggieri et al. [10]. Besides this, adsorption study was also conducted by researchers using different kind of absorbents in wastewater treatment of pharmaceuticals products [11].

In the past, activated carbon, activated alumina, silica gel and zeolites have been subjugated the commercial use of adsorption, due to their high degree of porosity [12]. The worldwide commercial demand for these adsorbent materials in 2001 is shown in Table 1.

Table 1 Commercial demand for adsorbent materials in 2001 [7]

Adsorbent	Commercial Demand (USD)
Activated carbon	1 billion
Zeolites	100 billion
Silica gel	27 billion
Activated alumina	26 billion

Adsorption acts as a separation process which means an involuntary process and an exothermic process that liberates energy. Thus, it is costly due to the need of chemicals, energy and the separation agent or sorbent. The surface of the adsorbent and the pore size of adsorbate molecule are playing the important role in determining the effectiveness of the adsorption process. Besides, a minimum amount of energy should be supplied to provide a good contact between the liquid and the surface of adsorbent under certain conditions to obtain the equilibrium state, thus encouraging or limiting the diffusion limitations [7].

The adsorption process consists of four steps as shown in Fig. 1. The first step will be the bulk solution transport. This step involves the movement of the substance to be adsorbed through the bulk liquid to an extremely thin surface layer of the adsorbent. This is followed by the second step, film diffusion transport, whereby the substance is diffused to the entrance of the pore of adsorbent through the stagnant liquid film. In the third step, pore transport will occur. In this step, the substance will be adsorbed through the pores and along the surface of the adsorbent. Lastly, the forth step will be the adsorption in which the adsorbate adheres to the surface of the adsorbent at an available adsorption site [13].
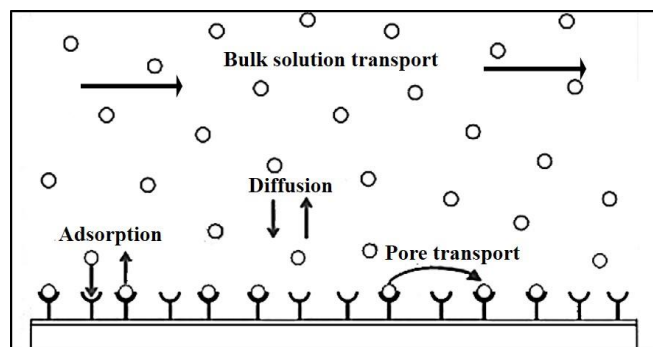

Fig. 1 - Schematic diagram of adsorption process

2.1 Mechanism of Adsorption

The term adsorption can be described by two kinds of adsorption mechanisms: chemisorption (chemical adsorption) and physisorption (physical adsorption). Chemisorption is a type of adsorption whereby the attraction between the adsorbent and adsorbate through the formation of a chemical bond with shorter bond length, resulting in releasing energy which is known as an exothermic process. This type of adsorption involves high adsorption energy which is higher than 1 eV per adsorbent molecule. Therefore, desorption is impossible or may need a high amount of energy to reverse the process for recycling the adsorbent.

As for physisorption, it is the second type of adsorption whereby the attraction between the adsorbent and adsorbate through the Van der Waals interactions. Physisorption is industrially favored due to the low adsorption energy which is lower than 1 eV per adsorbent molecule, thus requiring shorter time than that of the chemisorptions. In addition, the simplicity of the desorption process will be enhanced [14]. The adsorption process is usually controlled by physical forces (Van der Waals forces, hydrogen bonds, hydrophobicity, polarity and steric interaction, dipole induced dipole interaction) [6], with some exception of chemisorptions. The differences of physisorption and chemisorptions are summarized in Table 2.

Table 2 - Properties of physisorption and chemisorptions [36]

Physisorption	Chemisorption
• Multilayer adsorption	• Monolayer adsorption
• Low degree of specificity	• Depends on the reactivity of adsorbent and adsorbate substance
• Desorption is possible as adsorbed molecule keep its identity	• Desorption is impossible as adsorbed molecule loses its identity
• Exothermic	• Exothermic or endothermic
• System reaches thermodynamic equilibrium rapidly	• Activation energy is involved and system may not reach equilibrium

2.2 Adsorption Isotherms

Adsorption is also described via isotherms. The relation between the quantity of adsorbate on the adsorbent and the concentration is known as the adsorption isotherm which can be described by the following equation. There are two conditions to be met: (i) the various reaction equilibrium of retention is reached, and (ii) all the physic-chemical parameters are constant. The word "isotherm" is related to the effect of the temperature on the sorption reaction where the temperature remains constant [15].

In the previous work by Limousin and his co-researchers [16], it states that when the retention of a solute on solid particles is investigated, the remaining solute concentration of the compound C (mol/L or kg/L) can be compared with the concentration of this compound retained on solid particles Q (mol/kg or kg/kg). In Fig. 2, the concentration of the compound retained on solid particles Q is calculated by the difference between the initial solute concentration (C_{ao} or C_{bo}) and the final solute concentration C only if the initial solid concentration (Q_{ao} or Q_{bo}) is negligible or previously measured [12].
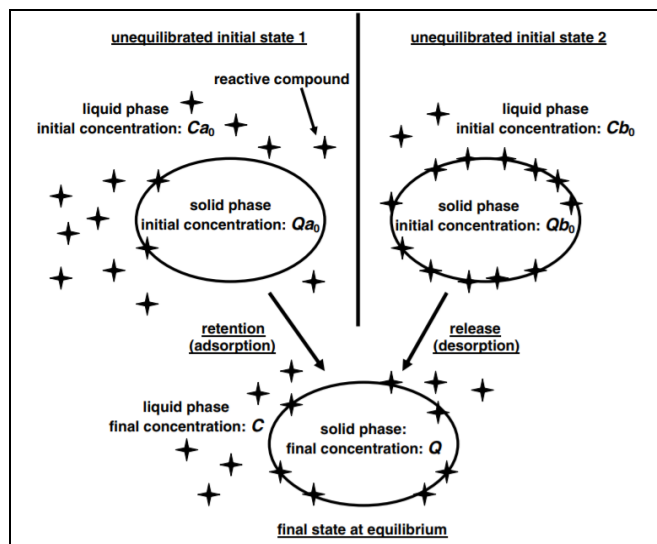

Fig. 2 - Schematic views of the adsorption and desorption phenomena [16]

In the retention stage, the solid concentration at equilibrium Q (mol/kg) is defined in Eq. (1), where V is volume of solution (L), m is solid mass (g), C_{ao} is initial solute concentration (mol/L), C is final solute concentration (mol/L) and Q_{ao} is concentration of the compound initially retained on the solid (mol/kg).

$$Q = \frac{V}{m}(C_{ao} - C) + Q_{ao} \tag{1}$$

For the case of a release stage of a compound which is initially retained on the solid phase, the quantity of this initially retained compound Q_{bo} must be measured in advance. Then, the solid concentration at equilibrium can be calculated using equation (1), replacing C_{ao} by C_{bo} and Q_{ao} by Q_{bo} [16].

Adsorption isotherm is important in explaining how solutes interact with adsorbents, thus optimizing the use of adsorbents. In the current development, various types of isotherm models have been developed to describe the process of adsorption. Langmuir and Freundlich isotherms are the two common adsorption isotherms used to explain the equilibrium characteristics of adsorption [17].

2.2.1 Langmuir Isotherm

The Langmuir isotherm model is based on a few assumptions: (i) the maximum adsorption occurs when there is a saturated monolayer of solute molecules exist on the surface of the adsorbent, (ii) the energy of adsorption on the surface is uniform, and (iii) there is no transfer of adsorbate molecules in the surface plane [18].

Langmuir isotherm is applied well to physical and chemical adsorption when saturation is reached. The linear form of Langmuir isotherm is defined as:

$$\frac{C_e}{q_e} = \frac{1}{bQ_o} + \frac{C_e}{Q_o} \tag{2}$$

where: C_e is equilibrium concentration of adsorbate (mg/L), q_e is amount of adsorbate adsorbed per unit mass of adsorbent (mg/g), Q_o is empirical Langmuir constant (related to maximum adsorption capacity), and b is empirical Langmuir constant (related to rate of adsorption).

2.2.2 Freundlich isotherm

The Freundlich isotherm model is an empirical equation for describing the physical adsorption of solutes from liquid to solid surface. There is a multilayer adsorption and there is no limit to the amount adsorbed. In the case of heterogeneous surface energies, Freundlich isotherm is better for adsorption isotherm which is defined as:

$$q_e = K_F C_e^{1/n} \tag{3}$$

where: q_e is amount of adsorbate adsorbed per unit mass of adsorbent (mg/g), K_F is empirical Freundlich constant or capacity factor (mg/g), C_e is the equilibrium concentration of adsorbate (mg/L), $1/n$ is Freundlich intensity parameter. $1/n$ is an index of diversity of free energies related to the adsorption of the solutes by multiple components of a heterogeneous adsorbent. When the value is approaching 1, the isotherm is linear and the system has a constant free energy at all adsorbate concentrations. As for a value below 1, it indicates a normal Freundlich isotherm whereby the cooperative adsorption occurs if the value of $1/n$ is more than 1 [19]. The constants can be determined by plotting $\log q_e$ against $\log C_e$ which is shown below.

$$\log q_e = \log K_F + \frac{1}{n}C_e \tag{4}$$

2.3 Factors Affecting Adsorption Process

The process of adsorption is affected by several factors such as the internal surface area of adsorbent, pH, the mass of adsorbent, the initial concentration of adsorbate and temperature. As the adsorption process takes place on the surface of the adsorbent, thus its pores size on the surface is playing an important role. At a given temperature (below 30 °C), the efficiency of adsorption increases with the increase of the internal surface area of adsorbent [6]. Another important factor includes the pH value of the solution. The pH causes the ionization of active sites, hence affecting the removal performance. As the value of pH is below 3, there will be a little sorption due to the carboxylic sites are mainly protonated, thus causing less sites for the adsorption process. As pH increases, the efficiency of adsorption increases due to the deprotonation, thus increasing the negative charge density on the sorbent surface [20].

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In addition, the mass of adsorbent and the initial concentration of adsorbate might affect the efficiency of the adsorption process too. As the mass of adsorbent increases, the efficiency of adsorption increases [21]. Besides, the adsorption efficiency also increases with the initial concentration of the adsorbate [22]. Adsorption process may also be affected by the temperature changes during the adsorption process. As the temperature increases (below 30 °C) causes the stretching of adsorbent, thus there will be more active site for the adsorption process [20].

Table 3 - Removal of heavy metals by using different forms of keratin material made from chicken feathers

Heavy Metal	Initial Conc. of Heavy Metal (mg/L)	Removal Percentage (%)	Modification of Chicken Feather	Ref
Cu	10-100	75.0	Chicken feather particle treated with NaOH and dodecyl sulphate	[22]
Zn	10-100	31.3		
Cu	10-40	48.8	Ultrasonic processing	[39]
Pb	10-40	83.5		
Hg	10-40	97.6		
Zn	10-40	3.8		
Cd	10-40	17.0		
Ni	10-40	10.1		
Ca	50-1000	72-94	Keratin amino acid immobilized silica particle	[21]
Fe				
Mg				
Mn				
Pb	10-200	83.0	Acidic treatment with addition of ethanol	[20]
Cr	10-80	90.0	Alkaline treatment with addition of epichlorohydrin and ethylenediamine	[40]
Cu	10-80	7.5		
Cr^{6+}	10-80	90	Chicken feather treated with epichlorohydrin and ethylenediamine	[41]
Cr	100	38.0	Hybrid polyurethane membrane with 15 weight percent of chicken keratin (resin and fiber)	[42]

3. Chicken Feather as Adsorbent

There are many types of adsorbents that had been used in the world. The effectiveness of an adsorbent can be explained in term of the adsorption capacity, adsorption rate as well as the possibility of regeneration [7]. Recent studies so far have reported that the fibrous proteins contained in some wastes from the animal processing industry can be used as the sorbents for wastewater treatment [5]. Chicken feather is one of the main byproducts in poultry farming which is produced in a significant amount with no investment. However, most of the chicken feathers are treated as waste products [23], [24]. People used to dispose the waste product of chicken feather by incineration and underground burial.

In fact, the chicken feather is a potential low-cost adsorbent since the worldwide poultry consumption has generated a huge amount of chicken feather annually. Due to its interesting properties and its high availability as environmental waste, researchers have used it in many applications. Results have proven that the chicken feather fiber effectively removes several pollutants from the aqueous solutions, especially the heavy metals [5]. Table 3 shows the removal of heavy metals by using different forms of keratin material made from the chicken feathers. As for the removal of some colorants and the organic toxic compounds, the chicken feathers are also found to achieve satisfactory results for the sorption purpose [20].

3.1 Chicken Feather Composition and Morphological Structure

Chicken feathers act as a protective covering for chicken from outside weather and physical objects. Chicken feathers which occupied around 8.5% of the total mass are composed of approximately 91% keratin, 8% water and 1% lipids [25]. A feather has a protein content of about 84% along with the inorganic constituents (calcium, magnesium, selenium, zinc and others). However, the strong disulfide bonding of the amino acids as well as the high keratin content, make the raw feathers to have a very low digestibility of around 5% and become relatively insoluble [3].

Unlike any other natural or synthetic fibers, chicken feathers have a unique structure. A feather is made up of two parts, namely the fibers and the quill. In fact, a feather mainly consists of three distinct units (Fig. 3). The rachis which is the central shaft of the feather attaches the barbs and the barbules which are the secondary and tertiary structures of the feather [26]. The barbs and the barbules are known as the chicken feather fibers (CFF), where the fiber diameters are found to be in the range of 5-50 μm [25]. As for the feather rachis, it is stiff and thick, thus it is not suitable as a natural protein fiber.
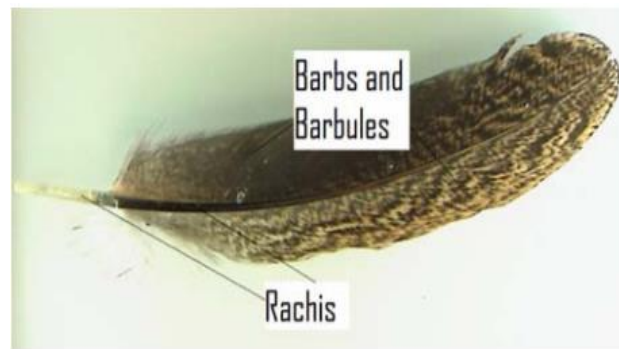
Fig. 3 - Three structural levels of the feather [26]

Fig. 4 and Fig. 5 respectively show the scanning electron microscope (SEM) of the tertiary structure of feathers and the cross-section of a barb, showing the hollow honeycomb shaped hollow cells. The barbules have lengths of around 0.3 – 0.5 mm and have hooks at their ends [26]. The feather barbs are more flexible than the rachis and able to twist as well as bend even when groups of barbs are together. The features of the flexibility, length and strength make the feather barbs suitable as the natural protein fibers. Moreover, the unique cross-section of barbs as shown in Fig. 5 is not found in any natural protein fibers such as silk, wool and others [26].
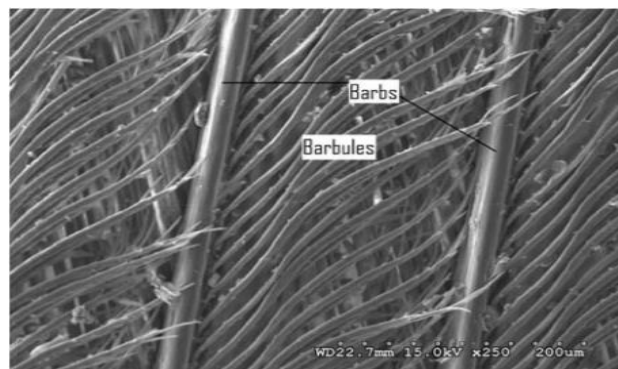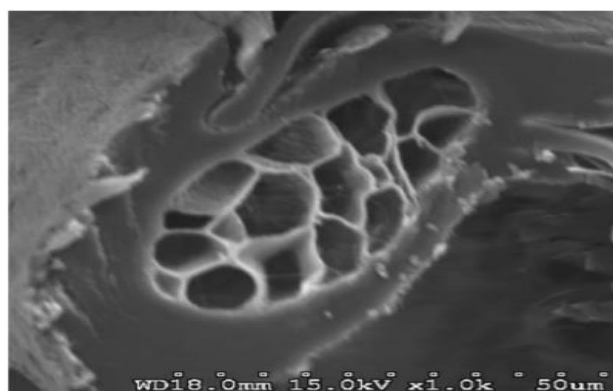

Fig. 4 - Tertiary structure of feathers [26]

Fig. 5 - Hollow honeycomb shaped hollow cells in a barb [26]

3.2 Chicken Feather Properties

Chicken feathers have many interesting properties which had been explored and revealed by the other researchers and has a potential to be a good precursor for many application [26]. The main component of the chicken feather is keratin, a protein that possesses the unique physicochemical properties for the sorption process of metallic species [5]. The biomolecules of amino acids act as reactive sites of having a natural affinity towards metals, organic compounds

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and gases. Additionally, keratin is playing an important role in the enhancement of the advantages of chicken feathers. It had improved the tensile strength, structural toughness, water insolubility and stability over a wide range of pH [20].

Besides, α-helix keratin is the formation of fiber' backbone from the flexible and long fiber, which is attributed to mimic the amino acid sequence of α-helix, while β-sheet keratin is the fiber that acts to fill the spaces between the α-helix tubes. The structural toughness of the chicken feather is contributed to the hydrogen bonding between each segment of the amino acid chains [27]. The bio origin material like chicken feather also has a lower density of approximately 0.8 g/cm^3 than water due to the honeycomb-shaped in the barbs, resulting in light weight [28]. The cross-section of honeycomb-shaped hollow cells in the barb provides good air and thermal insulating properties and increases the resistance to compressibility as well [29]. Overall, the above-mentioned interesting properties such as the low density, excellent compressibility and resiliency of feather barbs had made them a unique fiber.

3.3 Activation Methods

Activation methods enhance the effectiveness of chicken feather as a potential adsorbent by providing them with high pore volume and microporosity as well as improving their surface area ranging from 100 m^2/g to 200 m^2/g. These advantages are important for the adsorption or separation process, purification and the storage of liquids and gases [27]. There are two types of activation methods by thermal and chemical treatment of chicken feather fiber to enhance their structural changes for a better adsorption [27].

3.3.1 Chemical Treatment

The first method is the chemical treatment. Chemical treatment is used to enhance the chicken feather fiber as a potential low-cost adsorbent by modifying the reactive site to be more effective in the adsorption process. The barbs were pre-treated by hydrogen peroxide for 24 h and washed with a copious amount of distilled water to remove the adhering impurities in feathers, followed by a drying process for overnight [3]. Besides, another alternative procedure included a washing process of the chicken feather with detergent, subsequent by aqueous ethanol (20%, v/v) for removing the organic residues [5]. In addition, active amino acids of chicken feather towards the metal uptake were also provided through the alkaline treatment with NaOCl and NaOH solutions as well as the immobilization of silica on the surface [21]. Table 4 shows the preparation of chicken feathers by chemical treatment.

3.3.2 Thermal Treatment

The second method is the thermal treatment. The effect of pyrolysis on the chicken feathers is studied on the morphological changes include side-chain degradation [27]. Pyrolysis process is an irreversible reaction which occurs by the thermal treatment in the absence of oxygen [30]. In the previous research by Senoz and Wool [27], a two-step pyrolysis approach is established to enhance the porous nature of chicken feather fiber and convert its quality into high temperature resistive. In the pyrolysis, the first step is the heat treatment of chicken feather at 215 °C which is below the keratin melting point with the purpose to study the effect of an isothermal treatment, and provide the good structure and mechanical strength for the fibers. As for the second step of pyrolysis (400 – 450 °C), this step is important to achieve a narrower pore distribution of the microporous material, which is less than 1 nm for the use of hydrogen adsorption [27].

Table 4 - Examples of preparation of chicken feathers by chemical treatment

Type of Chemical Activation	Reagent	Pollutant	Ref.
Acidic treatment	Hydrogen peroxide	Indigo Carmine	[3]
Alkaline treatment	Sodium dodecylbenzene sulphonate and 1-butyl-3-methylimidazolium chloride.	Cr (IV) ions	[24]
Acidic treatment	Aqueous tannic acid solution	Pb ions	[43]
Alkaline treatment	Sodium bisulphite (NaHSO$_3$), urea, and sodium dodecyl sulphate (SDS	Analytical grade methylene blue	[44]
Acidic treatment	Aqueous acetic acid and sodium bicarbonate (NaHCO$_3$)	Cu ions	[45]
Acidic and alkaline treatment	hydrochloric acid, sodium bisulphite solution and sodium hydroxide solution.	Acid blue-A dye	[46]

4. Application of Chicken Feather

The unique morphological structure of chicken feather enhances its interesting properties to be a low-cost adsorbent for different applications purposes. For instance, the chicken feather is used to remove the heavy metals ions,

petroleum hydrocarbons, dye treatment and act as a hydrogen storage. Besides, the keratin contained in the chicken feather plays important role in converting it to added-value products such as animal feed supplement.

4.1 Heavy Metal Removal

Chemically treated chicken feathers are studied and used widely in the treatment of wastewater which contains the polluting metals from industrial water such as copper, zinc, calcium, magnesium, iron, manganese, lead, cadmium and nickel which are shown in Table 5. Results had shown that chicken feather is found convincing to act as a low-cost and environmentally friendly sorbent for the heavy metal removal. The examples of heavy metals and their operating factors in the batch adsorption studies are shown in Table 5. Based on Table 5, it shows that the concentration of heavy metal, the mass of chicken feather, the pH value and the temperature are the common influential factors for the removal efficiency of heavy metal.

Table 5 - Examples of heavy metals and their operating factors in the batch adsorption studies

Heavy Metal	Preparation of Metal Solution	Vol. of Sample (ml)	Conc. of Heavy Metal (mg/L)	Mass of CF (g)	pH	Solution for Adjusting pH	Temp. (°C)	Shaking Speed (rpm)	Ref
Cu	$CuSO_2.5H_2O$	50	10-50	0.25	-	-	-	-	[22]
Zn	$ZnSO_4.7H_2O$		20-100						
Ca	$CaCl_2$	100	50-1000	0.2-1.5	2-9.5	-	20-55	150	[21]
Mg	$MgCl_2.6H_2O$								
Fe	$FeCl_2.4H_2O$								
Mn	$MnCl_2.4H_2O$								
Pb	$Pb(NO_3)_2$	15	10-200	0.06	2-5	Diluted acid solution	25-40	210	[20]
Zn^{2+}	Nitrate salt, $Zn(NO_3)_2.6H_2O$	15	1-100	0.06	3-5	Diluted NHO_3	25,30,40	-	[5]
Pb	$Pb(NO_3)_2$	100	5	0.3	4-8	0.1N HCl, NaOH	-	-	[2]
Cd^{2+}	Nitrate salts	15	10-200	0.06	2-5	Diluted HNO_3	25,30,40	-	[47]
Ni^{2+}									

4.2 Petroleum Hydrocarbons Sorbent

The oil industry is a sector that has given residence to a large contamination of hydrocarbons. Chicken feather has been studied to be used as a spill clean-up sorbent. The removal of petroleum hydrocarbons is studied in the keratinolytic mixed culture which is a system containing keratinous chicken feathers at different concentrations of petroleum hydrocarbons [31]. The removal is affected by the petroleum holding capacity of CF and the results are shown in Fig. 6.
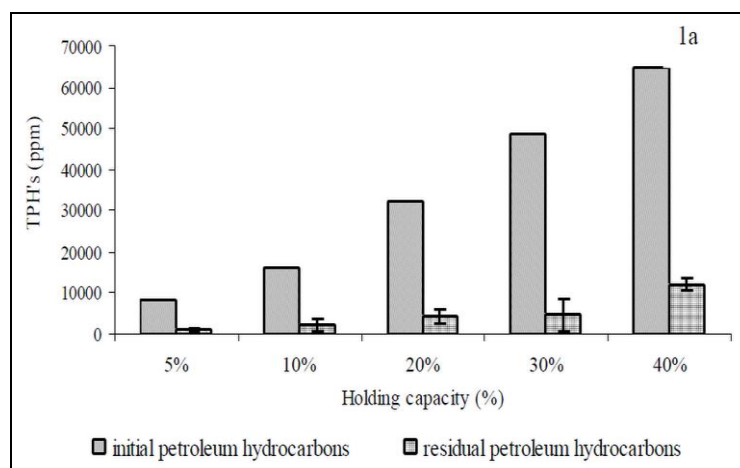

Fig. 6 - Petroleum hydrocarbons removal using chicken feather as sorbent by keratinolytic mixed culture [31]

4.3 Animal Feed

Chicken feather keratin can also be used as an animal feed supplement [32]. Lime is found to be a potential agent in the treatment and solubilization of chicken feather protein. In the study that had been carried out by Coward-Kelly and his co-workers, lime (calcium hydroxide) was applied in the treatment of chicken feather keratin to obtain a liquid product that rich in polypeptides and amino acids. Results indicate that soluble hydrolyzed chicken feather keratin could be the main protein source for ruminants.

The production of feather meal by heat processing has been demonstrated by King'ori [33]. The heat treatment process from 115 °C to 145 °C makes the feather meal safe for animal feeds for a wide range of animal species, including fish and shrimp. The product after the heat treatment is an aseptic protein product which is free of the potential biohazards and the environmental threats [33].

4.4 Dye Treatment

Mittal had studied a lot in dye removal in his journeys [3], [34], [35], [37]. Table 6 shows the constants and operating factors chosen in the kinetic studies.

The dye that was considered is Malachite Green, a water-soluble dye which belongs to triphenylmethane family [34]. It is widely applied to dye cotton, leather, silk, wool and others. In addition, Mittal [35] also successfully removed Brilliant Blue FCF, a hazardous water-soluble triphenylmethane dye from wastewater by using the treated chicken feather. In the batch studies, the results significantly indicate that approximately 70% to 100% removal of dye (1×10^{-5} – 1×10^{-4} M) was obtained by hen feathers. Accordingly, a well-fitted linear relationship was obtained for the Freundlich and Langmuir adsorption isotherm models, suggesting an endothermic, spontaneous and feasible adsorption.

Later in 2007, the ability of chicken feather to remove Tartrazine and Indigo Carmine from aqueous solutions also has been studied. Last but not least, Chen et al. [38] investigate the removal of acid blue-A dye by using the chicken feathers as adsorbent and the results shown that the chicken feathers can be efficiently used to remove hazardous dye without detrimental to the water quality. Overall, feathers could be used as a valuable, effectual and economical adsorbent in the adsorption.

Table 6 - Constants and operating factors in kinetic studies in removal of dyes

Dye	Vol. (ml)	Conc. of Dye (M)	Mass of CF (g)	pH	Temp (°C)	Ref.
Malachite Green	25	$1\text{-}10 \times 10^{-5}$	0.01-0.2	3-7	30,40,50	[34]
Brilliant Blue FCF	25	$1\text{-}10 \times 10^{-5}$	0.01-0.2	2-6	30,40,50	[35]
Tartrazine	25	$1\text{-}10 \times 10^{-5}$	0.005-0.025	2-6	30,40,50	[3]
Indigo Carmine	25	$1\text{-}10 \times 10^{-4}$	0.005-0.05	2-6	30,40,50	[37]

4.5 Hydrogen Storage

Pyrolyzed chicken feather fibers which are known as PCFF were prepared by a two-step pyrolysis process. From the work done by Senoz and Wool [4], the PCFF revealed a high H_2 adsorption uptake owing to the nature of micropores. The PCFF exhibited a significant H_2 adsorption affinity under the experimental condition with low pressure and temperature of 77 K. According to the H_2 adsorption analysis, the findings showed that two kinds of adsorption sites, which is micropores in the fibers and pores accessible to the H_2 molecules, are available on the surface pyrolyzed chicken feather fibers

5. Future Perspectives

The development of low-cost adsorbent boosts the bright future of the adsorption process. Chicken feather is widely available as the poultry waste and shows its excellent performance as a low-cost adsorbent. Although there are many studies on the applications of the chicken feather, the chicken feather is still not being used in a large scale as an adsorbent. This may be due to the gap in the knowledge about the extensive utilization of the chicken feather as well as the management of the exhausted chicken feathers. As discussed in this review paper, the previous studies mostly employed this adsorbent for heavy metals removal by chemical activation. The potential of the chicken feather by the heating treatment or known as pyrolysis needs to be investigated and explored in detail. Furthermore, the morphological structures and properties of the chicken feather also enable it to go beyond the adsorbent's role. The fibers and protein in chicken feathers will be playing the important roles in converting the chicken feathers into value-added products. Further studies on the chicken feather will be completed in future.

6. Conclusion

Literature shows that chicken feather which is the waste by-product from the poultry farming is the potential low-cost adsorbent. Many studies had done to evaluate the capabilities of the chicken feather as an adsorbent with different

preparation methods. The development of chicken feather as a low-cost adsorbent brings a great solution on the environmental problems and waste management. From the critical evaluation of this review paper, it shows that the unique structure and interesting properties of the chicken feather make it as a potential low-cost adsorbent which is having a wide range of advantages and applications.

Acknowledgement

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